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THE NONLINEAR THERMODYNAMICS OF METEORS, NOCTILUCENT CLOUDS, ENHANCED AIRGLOW AND GLOBAL ATMOSPHERIC CIRCULATION

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Abstract

Two types of fundamental topological junctions of elements are deduced from a nonlinear thermodynamical model. Using this scheme we examined the possibility of a causal relation between fireballs and faint meteors as nonlinear sources on the one hand, and noctilucent clouds (NLC) and Hoffmeister´s enhanced airglow (EA) as complementary formative processes in the middle atmosphere and ionosphere, on the other hand. The principal role of the global atmospheric circulation in this relation is demonstrated. Such circulation in the mesosphere appears to prevent the neutral dust dissipated by fireballs from becoming an efficient agent in NLC generation. In this case, the behavior of ionized material deposited by both the bright and faint meteors is more probably controlled, as shown from the annual variation of the E_s layer by the darkness of lunar eclipses and the global circulation of the lower thermosphere. The role of fireballs and neutral dust might be more significant as a source of the EA phenomenon.

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From a recent investigation by the author of coincidences between very bright meteors -- fireballs and noctilucent cloud (NLC) occurrence, it appears that practically no such coincidences exist (Paper II, RAJCHL, 1985). The question arises, what might be the cause of this negative result?

To answer this question, we have used a more general approach. From the author´s thermodynamic model of meteors, published in Paper I (RAJCHL, 1979), it follows that an intimate connection does exist between the so-called compound thermodynamic system and the Clifford algebra representation. This leads to the conclusion that it is not only in the dissipative phase of meteor interaction that the role of the atmosphere is crucial. However, especially in the following formative phase, when deposited meteor material acts on the atmosphere, it is the dynamics of the atmosphere, represented in the model by vector products (namely, rotors contained in the Clifford product (CASANOVA, 1979)), and realized to the first approximation by the global circulation of the mesosphere and lower thermosphere, which is of fundamental importance (Paper II.)

It is widely accepted that the nucleation process leading to NLC generation in middle latitudes is nonhomogeneous and of a nonlinear nature (GADSDEN, 1982). Therefore, the nonlinear extension of our former thermodynamic approach, as used in Paper II, is necessary. Two forms of such extension are used: the network thermodynamics representation with bond graphs (OSTER et al., 1973) and the time derivative of the original linear compound system of Paper I; thus, for such a nonsecond form of extension this means that the overall change of entropy production in such a nonlinear compound system S becomes proportional to the sum of terms $\dot{X}J$, $X\dot{J}$, $\dot{X}^*J^*$, and $X^*\dot{J}^*$; X and J are the forces of interaction with the atmosphere and the flow of meteor matter, respectively (represented e.g., by the mean velocity) in the dissipative phase of the meteor -- atmosphere interaction, and X* and J* are the same quantities for the formative phase. In other words, the formative process in the atmosphere, as induced by meteors, is represented by the response of the atmosphere to the dissipation of meteor matter as a source. The nonlinear compound system contains two different types of dissipative and formative terms.

Both above-mentioned thermodynamic nonlinear representations contain fundamental topological features in the form of serial (s) and parallel (p) junctions of sources and responses. From Paper I it follows that the following are acceptable nonlinear sources: fireballs and faint meteors. The atmosphere is considered global: both the northern and southern hemispheres are included.

From observational data collected by the European Network for fireball photography in the northern hemisphere (CEPLECHA, 1977), and those published in the SEAN Bulletin (1976-1980), we found that the maximum of a number of fireballs is in winter in the northern hemisphere. As no systematic fireball observation data exist for the southern hemisphere, we used an intimate analogy between fireballs and meteorites to estimate their approximate number in this hemisphere. A recent study by HALLIDAY and GRIFFIN (1982) shows that the maximum of fireballs (if analogous to meteorites) would occur in the southern hemisphere a half year later than in the northern. Thus, it seems that fireballs manifest -- in respect to both hemispheres -- a nonsimultaneous, i.e., serial junction of maxima of occurrence.

On the other hand, faint meteors represented by radar meteors (ELFORD, 1965) show their number maxima simultaneously in winter and in summer in both hemispheres, therefore in a parallel junction.

From Paper III (RAJCHL, 1985), it is apparent that possibly two adequate responses to the above-mentioned two sources may be observable in the form of NLC and the so-called enhanced airglow (EA) phenomenon (HOFFMEISTER, 1958). Both phenomena constitute a complementary s-p system, analogous to the system of soruces. That is to say, the NLC are present only in the summer season in both hemispheres (GADSDEN, 1982), i.e., in a serial configuration, while EA are observed simultaneously in both the northern and southern hemispheres, therefore in a p-junction.

Now, if we introduce the global circulation of the mesosphere and lower thermosphere connected with subsequent vertical transport, we obtain throughout the whole year a situation demonstrated schematically in Table I (global circulation) and Table II (vertical transport) (ILICHOV and PORTNYAGIN, 1977, Papers II and III). According to NECHITAILENKO (1979), the direction of vertical transport is the same for netural and ionized material only for heights < 80 km. Higher in the atmosphere it is mutually opposite for both species.

Table I.

Season		winter	summer	summer	winter
Hemisphere		north.	south.	north.	south.
Height in km	> 80	W E W		W E W	
	< 80	W	E	E	W

W - cyclonic type of global circulation
E - anticyclonic type of global circulation

Table II.

Season		winter	summer	summer	winter
Hemisphere		north.	south.	north.	south.
Height in km	> 80	↑ ⇓	↑ ⇓	↑ ⇓	↑ ⇓
	< 80	↑	↓	↓	↑
Observed Phenomena		EA	EA NLC	/EA/NLC	/EA/

/EA/ means the EA of smaller intensity.

↑ means transport of neutral material

⇓ means transport of ionized material

The Tables show that the majority of fireballs, which deposit ablated material (neutral dust and ions) at altitudes lower than the NLC level, is, because of the prevalent downward global transport in summer, incapable of directly influencing the NLC nucleation process. This conclusion is confirmed also by the minimal dust concentration in the whole atmosphere up to the 120-km height level in summer, as deduced from lunar eclipses photometric observations (LINK, 1955). Moreover, if we estimate the mean velocity of vertical transport from the delay between the global circulation reversal and the subsequent change of dust content in the atmosphere, we find a value of ~ 4 cm/s, i.e., the same value as obtained by other methods.

The meteor material transported upwards to the 120-km level in winter is more likely to be involved in the EA phenomenon, while the downward transport of ionized material, deposited mainly by faint meteors in heights about 100 km, it probably the source of NLC nuclei. This result seems to be substantiated also by the observed downward transport towards the E_s layer in summertime (ROYRVIK, 1983). Another fact may support the ions as the main cause of NLC nucleation: the short break in the global circulation of the lower thermosphere caused by the spring type of circulation result in upward ion transport. The return of the thermospheric circulation to westerly at the end of May, or the beginning of June, renews the downward transport of ions into the NLC level. This time coincides very closely with the beginning of the season of NLC observations in midlatitudes. Thus, it seems that in addition to the low temperature, this onset of downward transport of ions may be another important condition for the occurrence of NLC.

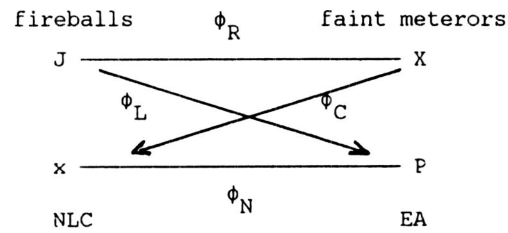
Thus, we may conclude that: 1) Even though such "local" processes as turbulence, internal gravity waves, etc. may be of higher intensity than the relatively fainter global-circulation-induced transport processes, to a first approximation, the global circulation may lead to consequences of fundamental importance relating meteors to atmosphere phenomena.

2) It seems that deposition of meteor ions is connected with NLC initiation, and neutral dust with EA phenomena.

3) If secondary relations are omitted, the fireballs (s-sources) are connected with EA (p*-phenomena) and faint meteors (p-sources) with NLC (s*-phenomena); so that some type of a cross-complementarity s-p*, p-s* arises. For the principal interactions (the secondary ones are omitted) we obtain the following nonlinear thermodynamic scheme:

$$\begin{tikzcd} s \arrow[r, leftrightarrow] \arrow[dr] & p \arrow[dl] \\ s^* \arrow[r, leftrightarrow] & p^* \end{tikzcd}$$

An analogous scheme is known also in network thermodynamics (OSTER et al., 1973); when adapted to our problem, it is of the following form:



where X,J,x and P are forces, flows, displacements and impulses, respectively. ϕ_R, ϕ_L, ϕ_C, ϕ_M are individual connections, represented in the form of the so-called constitutive relations:

$$\phi_R(X,J) = 0, \ \phi_L(J,P) = 0, \ \phi_C(X,x) = 0, \ \phi_M(P,x) = 0$$

It is apparent that both schemes are interrelated. Combining the results of the present paper with those of the network thermodynamics of OSTER et al. (1973), we may obtain some additional conclusions:

4) The sources, in the same way as energetic transactions, are characterized by the constitutive relation $\phi_R(X,J) = 0$, or by dissipation $(X.J) \neq 0$. The product $(P.x) \neq 0$ is typical for responses. Connections between sources and responses are then realized, in general, by the (X.x), i.e., virial and (J.P)-impulse products. Applying this knowledge to our case, we find that the connection between faint meteors and NLC (scheme II) is of the form of this virial, especially as it applies to the NLC nucleation, as widely accepted. On the other hand, the impulse interaction is valid for the fireball-EA connection. Unfortunately, no more can be said about the precise mechanisms of either the virial or the impulse interactions from this scheme alone.

5) The quantities that are constant are the flows J for fireballs and forces X for faint meteors; for NLC there are displacements x; for EA impulses, P.A comparison with individual terms of the nonlinear compound system implies that the quantities conjugate to the above-mentioned constants, i.e., X to J for fireballs, J to X for faint meteors, etc. can change with time. Therefore, from the schemes (I) and (II) and the nonlinear compound system terms all combined together with observations, we may infer that, e.g., $\dot{X}J$ corresponds to fireballs and the s-junction and $X\dot{J}$ to faint meteors and the p-junction, and so on.

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